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ACQUIRING EXPERTISE IN OPERATIONAL PLANNING: A BEGINNING

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U.S. ARMY COMMUNICATIONS-ELECTRONICS COMMAND
Fort Monmouth, New Jersey

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ACQUIRING EXPERTISE IN OPERATIONAL PLANNING: A BEGINNING

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1 August 1986

This report describes research conducted as part of ARES, a basic research and exploratory development project of the US Army Communications/Automatic Data Processing Center, US Army Communications-Electronics Command.

ABSTRACT

This paper presents the results of a series of knowledge-acquisition sessions conducted to characterize the practice of operations planning at the corps command level. The sessions were successful in developing an initial understanding of the function of a Course-of-Action. This understanding was then employed to develop a structure for a Course-of-Action which incorporated the desired functionality. Following this, the sessions concentrated on developing the knowledge structures required for creation of the Scheme of Maneuver, the principal element of the Course-of-Action structure.

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1. INTRODUCTION

During the winter months of 1985 and 1986 a series of intensive knowledge-acquisition sessions was held between scientists of the US Army Communications/Automatic Data Processing Center, US Army Communications-Electronics Command and the US Army War College. The objective of the sessions was to develop a knowledge-based characterization of the activities of officers of the corps G3 Plans Section, as practiced in the active-operations (battlefield operations are being conducted) environment. This characterization was to include: 1) a general description of the function of military plans in the operational environment; 2) a description of the product (a Course-of-Action) of the G3 Plans Section; and, 3) a detailed description of the knowledge planners bring to bear on problem instances they attempt to solve.

The emphasis on activities as practiced was a deliberate choice, concurred in by both the Communications-Electronics Command and the Army War College. The implication is that we were to attempt to capture both doctrinal knowledge and "expert" knowledge. With this decision it became important for the Army War College to identify "expert" planners: military officers experienced in developing operations plans in general, and with corps operations in specific. The individuals identified fit a similar professional mold: approximately twenty years of service in various heavy (mechanized and armored) units, a variety of command and G3/S3 (operations staff officer) positions in these units, corps G3 Plans Section experience, and recognized professional success (as exhibited by selection for attendance at the Army War College) in these positions.

Due to the limited period over which the sessions were conducted (December 1985 to March 1986) it was not possible to develop the complete characterization. Our initial analysis of the protocols has supported description of elements 1 and 2, which are presented in the second section of this paper. Additionally, we have been able to begin the knowledge description for one particular segment of the Course-of-Action, the Scheme of Maneuver. This knowledge description is presented in the third section of this paper. We conclude with a brief description of our plans for expanding this work.

This work has been conducted as part of the ARES Project [1], a basic research and exploratory development effort of the Communications/Automatic Data Processing Center, and as a Military Studies Project at the Army War College [2,3]. The results of this work have also supported the development of the initial ARES representation scheme [4].

2. COURSE-OF-ACTION GENERATION

Course-of-Action Generation at the corps level is best characterized as a complex planning activity. By contrasting the Course-of-Action Generation problem with the traditional AI planning paradigm we can identify a number of complexity sources. In this traditional planning paradigm a problem is represented by three characteristics. The first characteristic is the Initial State Description, a symbolic representation of the world in which the plan is to be executed. The second characteristic is the Goal State Description, a symbolic representation of the world after completion of plan execution. In both the Initial State Description and the Goal State Description, as well as any intermediate state descriptions developed during the course of planning, all essential elements of the world in which the plan is to be executed are symbolically modelled. The final characteristic is a set of Plan Operators, or symbolic representations of the actions which can be performed by the *single plan execution agent*, the only active element capable of changing the world state. In this symbolic representation of action is some indication of the essential elements of the world which must be present to permit performance of the action, and also some indication of the elements of the world that are modified by performance of the action. Accordingly, application of a Plan Operator to a symbolic state description results in the creation of another symbolic state description. With these three characteristics defined, an instance of a planning problem is to construct a sequence of Plan Operator applications which will transform a given Initial State Description into a given Goal State Description.

There are clear analogs in the Course-of-Action Generation problem to these problem characteristics, each of which introduces complexity issues not present in the traditional planning representation. The work to-date has identified four such issues, as follows: 1) the Mission, or Goal State Description, given planners provides an incomplete specification of the desired goal state; 2) the Battlefield Situation, or Initial State Description, given planners does not address the situation factors relevant to planning; 3) there are multiple, not a single, dissimilar execution agents, only some of which are controlled by the plan; and 4) the Plan Operators available to transform the Initial State Description into the Goal State Description do not represent actions which modify states. By examining these complexity factors it is possible to develop an understanding of the role played by a Course-of-Action in the conduct of military operations at the corps level.

2.1 THE ROLE OF A COURSE-OF-ACTION

The deficiencies inherent in the Goal State Description and Initial State Description force planners to devote considerable effort to understanding the Mission and Battlefield Situation, and how these will impact the planned operation. Although the nature of these interpretation tasks is not the subject of this paper [1], it is useful to examine these deficiencies to understand the planning process. The initial phase in the planning process is the Mission Analysis. The principal purpose of this phase is to define intermediate states and goal states for the subsequent planning effort. Mission statements are best characterized as a set of tasks (specified tasks [5]) to accomplish. For the purpose of this paper it is sufficient to state that each task identifies a number of elements of state which must be present in the goal state, or tactical posture at the conclusion of the operation. The result is a partially specified Goal State Description, which can be satisfied by a number of tactical postures.

Additionally, the higher command's operations plan will also contain (perhaps verbally) what is referred to as the Commander's Intent for the operation. From this planners must extract additional elements of state which fit two categories: 1) elements which must be present in an acceptable goal state, and 2) elements which cannot be present in an acceptable goal state. Collectively, these elements of state derived from the Mission and Commander's Intent define *Goal State Criteria* which must satisfy the requirements of the Course-of-Action Generation process for a Goal State Description.

The concept of an intermediate state relates to the AI planning concept of a necessary precondition (precondition wff [6]). Planners must identify those elements of state which are necessary preconditions for the accomplishment of state elements required to satisfy the Goal State Criteria. Additionally, planners must formulate a set of tasks (implied tasks [5]) to ensure these necessary preconditions are established. When finished, the Mission Analysis will have produced the complete set of tasks the corps will accomplish, and a set of Goal State Criteria which implicitly define allowable goal states.

The Course-of-Action Generation counterpart to the Initial State Description is the Battlefield Situation, which is normally described as a collection of *METT-T Factors* (Mission, Enemy Forces, Terrain and Weather, Troops Available, or Friendly Forces, and Time Available). The Mission Analysis contributes the Mission factors for a given planning problem. Of the remaining factors, Enemy Forces introduce the widest range of complexity sources. An examination of these sources will illustrate the deficiencies inherent in the Initial State Description provided by the METT-T Factors, and the effort which must be devoted to interpreting these factors.

The enemy force information available to planners is normally derived from two sources: 1) the Situation Map (SITMAP), a topographic map of the region under consideration with overlays depicting known and suspected enemy-force locations and identities; and 2) various order of battle (OB) files which describe the identified enemy forces in more detail. The quality of this information is a principal source of complexity. The OB and SITMAP are characterized by incompleteness, inaccuracies, and time-dated information. It is characteristic of the planning process that dependency on the specifics of OB and SITMAP information is avoided, and replaced by a dependency on information describing enemy force capabilites (operational activities the enemy is capable of performing), and intentions (a set of complementary capabilites, or a *plan*, believed to be the most likely to be performed) [7]. Developing intentions and capabilities is a difficult task. However, they provide higher-level descriptors of the enemy force which lessens the dependency of Courses-of-Action on specific elements of the enemy situation.

There is another characteristic of the enemy forces that motivates determination of capabilities and intentions. The enemy force consists of a number of active, dissimilar agents which attempt to produce state transformations which are in conflict with state transformations desired by the planner. Detailed consideration of the state transformation possibilities of each active agent is not possible. However, by developing intentions and capabilities planners can summarize the collective activities of the enemy forces into a set of time- , and location-dependent *Interest States*, or partial state descriptions which summarize enemy strengths at various points of the operation. One of the objectives of the Course-of-Action Generation Process will be to complete these Interest State Descriptions so that desired relative strengths are established at the critical points of the operation.

The presence of multiple, hostile, active agents is one contributor to the third source of complexity (multiple execution agents) in the Course-of-Action Generation problem. Additionally, a corps plan is meant to control the activities of a number of dissimilar (in capability) execution agents subordinate to the corps. In contrast, past AI planning research has focussed on development of plans for a single execution agent. The subgoal interaction problem (the PREREQUISITE-CLOBBERS-BROTHER-GOAL of HACKER [8]), a major issue in AI planning theories, is complicated when the planner must consider the simultaneous actions of a number of execution agents of varying capability. Various techniques which have been developed to explicitly manage subgoal interactions, such as abstraction spaces [6], debugging [8], procedural nets [9], goal regression [10], and constraint posting [11], are either complicated or made unworkable by the necessity to plan simultaneous activities.

Planning the activities of multiple, dissimilar agents is a complex activity for humans as well as automated systems. When compounded with the problem of multiple, dissimilar agents, not under plan control, and acting with hostile purposes, the difficulty of controlling potential interactions becomes too complex. Accordingly, the military solution avoids the necessity of detailed planning of actions of subordinate elements. Instead, military planners at the corps level will attempt to reduce their planning problem into a set of simpler planning problems, and provide a minimal framework for composing the solutions to these simpler problems into a solution to their problem *as the planned operation is being executed.* In consonance with this conception of operations planning, the Plan Operators available to planners do not represent actions which are to be performed by the subordinate forces. Instead, they serve to decompose problems and compose solutions. This characterization of the problem-solving activity associated with Course-of-Action Generation is practically identical to the problem- reduction problem-solving method contained in most AI textbooks [12,13]. This does not say that the Course-of-Action Generation problem is best formulated as a problem-reduction problem-solving activity. It does say that the problem-solving activity at the corps serves a purpose analogous to that of a reduction operator in the problem-reduction formalism.

From the above it is clear that the function of a Course-of-Action is two-fold: 1) to translate a given *Operational Problem* into a set of simpler Operational Problems, and 2) to provide a structure for coordinating the activities that result from executing the solutions to the simpler Operations Problems. Furthermore, it is useful to identify an Operational Problem as a 5-tuple consisting of the following: 1) a region of terrain over which the operation is to be conducted; 2) a set of enemy forces which may contest the operation; 3) a set of friendly forces with which to conduct the operation; 4) a set of tasks which must be accomplished; and 5) the Commander's Intent in pursuing the Operational Problems. To support this functionality a Course-of-Action must provide for identification and definition of each Operational Problem being created, and for specification of the framework within which solutions will be coordinated.

2.2 COURSE-OF-ACTION STRUCTURE

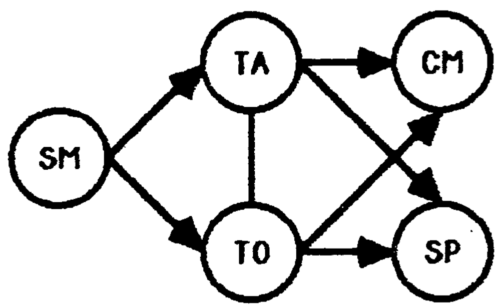
The knowledge-acquisition activities to-date have succeeded in defining a five element structure for a Course-of-Action which supports the requirements developed above. These elements are the Scheme of Maneuver, the Task Organization, the Task Allocation, the Command and Control Measures, and the Support Priorities. Additionally, a model has been developed which provides a partial order on the sequence in which elements of this structure are resolved, and which identifies the logical dependencies between these elements.

The Scheme of Maneuver describes and relates the functional activities of all subordinate elements of the corps. Additionally, the Scheme describes the relationship of the subordinate activities to the corps operation. In doctrinal terms, it is the unifying element of the Course-of-Action, and all subsequent activities of the corps are to be conducted in support of the Scheme of Maneuver. In the terminology developed in this paper, the Scheme of Maneuver serves to establish the framework for each of the Operational Problems being created, and for the activity coordination function the Course-of-Action must perform. Additionally, the Scheme of Maneuver provides the mechanism for communicating the Commander's Intent for the operation and for each Operational Problem being created.

Command and Control Measures perform a dual function. The first is to provide for synchronization between the Operational Problems by prescribing specific mechanisms for control of the battle and by allocating control assets to the Operational Problems. This function completes the framework, established by the Scheme of Maneuver, for coordinating the activities of the Operational Problems. The second function is to explicitly allocate regions of terrain to each of the Operational Problems. This terrain allocation, in turn, implicitly allocates enemy forces to each Operational Problem. In effect, the Command and Control Measures allocate enemy force capabilities and intentions to each Operational Problem created by the Scheme of Maneuver.

The Task Allocation assigns to each Operational Problem the tasks which are to be accomplished. The Task Organization allocates the maneuver (infantry, mechanized infantry, armor and cavalry) resources of the corps to each of the

Operational Problems. The Task Organization is the principal component of the Course-of-Action for specifying the friendly forces element of the Operational Problems. The other component which contributes to specifying the friendly forces elements is the Support Priorities. The friendly force resources allocated by the Support Priorities are the functionally specialized resources, such as fire support, air defense, engineer and logistic resources. The purpose of separating these two Course-of-Action elements is to reflect the dependence of one decision process on the solution of the other. To be more specific, the major decision issue associated with the Support Priorities is to correct deficiencies in a forces-allocated/tasks-allocated comparison for each operational problem.



SM = Scheme of Maneuver
TA = Task Allocation
TO = Task Organization
CM = Command and Control Measures
SP = Support Priorities

Figure 1 - Plan Structure Dependencies

There is a natural dependency network which exists between the elements of this Course-of-Action structure. This dependency network is described by the directed graph of Figure 1. In this graph the nodes represent the Course-of-Action elements and the arcs represent the dependencies. An arc which leaves one node and enters a second indicates that decisions concerning the second node will depend on decisions made about the first. Alternatively, solutions to the first node will interact with solutions to the second node. This dependency relation is also transitive: if solutions to one node interact with solutions to a second node, and solutions to the second node interact with solutions to a third node, then solutions to the original node will interact with solutions to the third node. Undirected arcs represent a two-way dependency, and force simultaneous consideration of the two nodes.

3. THE SCHEME OF MANEUVER

The Course-of-Action structure introduced above places the Scheme of Maneuver in a privileged position as the only element not dependent upon the solutions to other elements. The implication is that a Scheme of Maneuver for a particular problem instance can be developed independently of the other Course-of-Action elements and will provide a sufficient basis for development of the remaining elements. Accordingly, an attempt was made to examine the Scheme of Maneuver development process in order to develop the knowledge planners bring to bear in the development of a Scheme of Maneuver.

It was possible to characterize the Scheme of Maneuver development process as a hybrid classificatory and constructive process [14]. The classificatory aspects of the process select, from a large collection of known Scheme of Maneuver components, a smaller set for use in the current problem. The constructive aspects of the process assemble the selected components into a coherent Scheme of Maneuver. With this characterization it is clear that the relevant planning knowledge could be classified into three categories: 1) knowledge describing the primitive compo-nents of Schemes of Maneuver; 2) knowledge describing the selection process; and 3) knowledge describing the assembly process. Due to the time constraints on the joint project only knowledge categories 1 and 2 were further investigated. The last part of this characterization will not be further discussed in this paper.

3.1 SCHEME OF MANEUVER COMPONENTS

In enumerating the collection of known components it became apparent that they could be related to elements of a structure which is commonly used by military professionals to describe a Scheme of Maneuver. This structure is a direct translation of our experts' practical experience of describing an operation in terms of Who, What, When, Where, How and Why. For the remainder of this paper we will employ the terminology Agent, Activity, Time, Location, Method and Purpose to refer to these categories.

Although the structure of a Scheme is more complex than a simple listing of the Scheme elements and corresponding components, it proved useful to categorize the components by the Scheme element to which it could be applied. It is not the case that the components that apply to a Scheme element are mutually exclusive (i.e., selection of one component precludes the selection of any others). However, a number of components were found to be pairwise exclusive (i.e., two or more components cannot exist in the same Scheme element). The remainder of this section discusses the components by the Scheme element to which they may be applied.

Identification of the active agents is the purpose of the Agent elements of the structure. The components that apply to the Agent element are different from those that apply to the other Scheme elements in that they are not part of problem solving knowledge (do not reside in long-term memory [15]), but instead are part of the problem instance (reside in short-term memory [15]). Once this element has been developed the number of Operational Problems being created by the Scheme is determined.

The Activity elements of the Scheme structure identify a major form of maneuver, or the type of operation to be conducted. Additionally, special-purpose operations to be conducted in support of the major form of maneuver may be included in an Activity element. The components that apply to this element are the major operations types (e.g., attack, defend, prepare for future operations) and the specialized supporting activities (e.g., conduct reconnaissance, conduct screening operations). Activity components are part of a planner's knowledge structures.

The components that apply to the Time elements provide alternative means for specifying the time that an Activity component will be conducted. These components may relate to an Activity component in different manners (e.g., start times, completion times, temporal intervals). The variety of time components identified permit temporal specification in a number of modes, including: absolute times (e.g., specified hour, upon receipt), a time relative to the occurrence of another event (e.g., on order, upon completion of), and a bounded time (e.g., no earlier than, no later than). Time components are also part of a planner's knowledge structures.

The Location components provide alternative means for specifying the terrain over which an Activity component will be conducted. As with the Time components, a number of relation types may exist between the Activity and the Location components. The Location components also permit terrain specification in a number of modes, including: bounded regions (e.g., objective, designated region), unbounded regions (e.g., in zone, in sector), a direction (e.g., along axis, direction of attack), and a region specified by a relation to another region (e.g., relationship to a specified enemy forces, cardinal direction). Location components are also part of a planner's long-term knowledge structures.

The components discussed to this point are independent, in that selection of components from one element does not preclude the selection of any components from any other element. In contrast, most components that apply to the Method element are sensitive to the components selected for the Activity element, and this allows us to further categorize these components by the related Activity component. Within the Method components we also begin to see the pairwise exclusive relation between two or more components. As an example of this, we have identified a number of Method components which apply only to an attack Activity component. Most of these can be related into groupings of alternatives, where only one alternative can be (but does not have to be) selected from each grouping. The following partial listing illustrates these relations, with alternative Method components indicated by set notation:

ATTACK
{HASTY DELIBERATE}
{SUPPORTED UNSUPPORTED}
{MAIN SUPPORTING}
{MOUNTED DISMOUNTED COMBINATION}
{DEEP SHALLOW}
{NARROW BROAD}

Our initial analysis indicates the Method components may provide an object-based structure [4] for the Activity components, and we plan to capture this in our initial implementation as part of the knowledge structures.

The components that apply to the Purpose elements of the Scheme of Maneuver detail the Commander's Intent. Although the selected Purpose components may not be included in a disseminated Scheme (at a minimum it must be disseminated verbally), it is essential that they be identified as they provide the foundation for selecting the other five components. Purpose components provide the motivation for directing that a specific Activity component be conducted. Example Purpose components include: seize terrain, destroy enemy forces, deny terrain to enemy forces, and seize the initiative. It is interesting to note that, in general, the Purpose components are independent of the Activity components. Any form of maneuver (the Activity components) can provide the means for accomplishing any of the Purpose components.

When complete, a Scheme of Maneuver consists of a collection of *Activity Groups*. The complete Scheme is composed of an Activity Group for each Operational Problem being created (a partial Activity Group is created for the corps Mission Statement). An Activity Group consists of a single Agent component, and one or more Activity components. For each Activity component there are related Method, Time, Location and Purpose components. Although this is a complex structure for what essentially amounts to a few lines of text in a written plan, we feel it is the minimum necessary the capture the meaning of the Scheme.

3.2 COMPONENT SELECTION

We have been able to characterize the component selection process at two levels. The top-level characterization prescribes a loose ordering on the sequence in which components are selected for the elements. The lower level characterization addresses the manner in which components are selected for each element. We will present a general selection process which applies to each Scheme element, and then provide an indication of how this is accomplished for a specific element.

Figure 2 provides a graphic representation of the loose sequence which orders the component selection process. The sequence is loose in that problem-instance factors may dictate changing the prescribed order, or perturbing the order once the process has begun. In the absence of such complicating problem-instance factors the figure describes a default control mechanism for performing the selection process. This default sequence provides for initial selection of Purpose components, as they will provide the foundation for selecting the other components. Additionally, they may provide the justification for perturbing the remainder of the sequence. Time components are almost always selected last. The ordering also prescribes the selection of Activity and Method components together (the enclosing box), since the Method components tend to fill in the structure of the Activity components. The ordering of the Activity/Method pair, Location components and Agent components is not prescribed by the control mechanism, and must be determined in reference to the problem-instance factors. In the absence of any determining factor, it is common to select the Activity/Method components before the Location and Agent components.

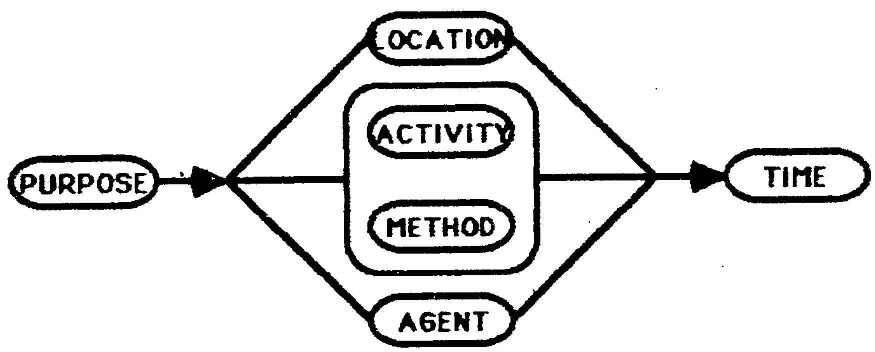


Figure 2 - Component Selection Sequence

The problem-instance factors referred to above are the METT-T Factors. A general selection process exists which can be applied to each component element. This process is best described by the following quote:

> "In selecting those parts (components) that will be assembled into a Scheme of Maneuver you must first consider all you know about the factors of METT-T. As you do this certain parts will be eliminated as being not applicable to the situation. This leaves a set of parts which are potentially useful for this problem. This set of parts is further analysed in the context of the METT-T factors to select those which are best for the situation." [16]

It is apparent from this quote that the appearance of certain METT-T Factors, or combination of factors, will eliminate components from further consideration. Following a round of elimination,the METT-T Factors are then used to choose, from those remaining components, the components to be assembled into the final Scheme. It follows that the METT-T factors exist in both supporting and denying relationships to the components.

Due to the impracticality of describing a given situation by listing the METT-T factors, planners find it useful to abstract the factors into higher level situation descriptors. These situation factors summarize selected aspects of the planning instance. We have identified six summary descriptors: Enemy Force Intentions and Capabilities (addressed earlier in this paper); Relative Strength, a comparison of enemy and friendly capabilities at specific time and location pairs; Relative Mobility, a comparison of enemy and friendly capabilities to move forces on the battlefield; Key Terrain, those terrain features which will have a significant impact on the operation; and Center of Gravity, an estimate of enemy vulnerabilities. Once developed, these summary situation descriptors provide the filter for selection of Scheme of Maneuver components.

To illustrate the use of summary situation descriptors in the selection of components we will further describe the Relative Strength descriptor. Relative Strength is a comparison of enemy- and friendly-force strengths and weaknesses, their ability to employ those strengths and attack the opposing force's weaknesses. The determination of Relative Strength involves all that is known about the METT-T Factors which describe the following: available enemy forces, available friendly forces, terrain over which both forces are to move and deploy, and the time available in which to move. Relative Strength is of particular utility in the selection (elimination and choice) of Method components. Of particular importance is the manner in which the Method components change Relative Strength measures. These components provide planners the mechanisms for establishing the required Relative Strengths at the decisive points of the battle. Actual and hypothesized Relative Strengths at various times and locations are the principal criteria for selecting Method components.

4. CONCLUSIONS

This paper has described the results of a pilot knowledge-engineering experiment, conducted by the Communications/Automatic Data Processing Center and the Army War College, which was designed to characterize the activities of the corps G3 Plans Section. This effort is complete in that the expert planners have departed the Army War College for positions which employ this expertise. The effort is also in-progress in that prototype implementation efforts based on the results of this project have been initiated and plans for other knowledge-acquisition projects between the Communications/Automatic Data Processing Center and the Army War College have been prepared.

The major results of this effort have been three-fold. The first is the formulation of the Course-of-Action Generation problem as an instance of the problem (or specification) refinement class of problems. Other common instances of this class include certain types of design problem-solving and automatic programming. The second significant result is the Course-of-Action structure, and resulting problem decomposition. The final result is the characterization of the Scheme of Maneuver development process as a hybrid classificatory and constructive process, and the associated identification of knowledge categories.

Much work remains to be accomplished. For the immediate future the efforts will be dominated by continued knowledge-acquisition projects between the Communications-Electronics Command and the Army War College. Building on the structure developed by this project, future projects will investigate three issues. The first is a continuation of the described project, and will attempt to complete the knowledge-level description of the Course-of-Action Generation process. The prototype being implemented will serve as a tool for completing this description. The second project will attempt to develop a knowledge-level description of the process of developing summary situation descriptors. This has been arbitrarily termed the Situation Assessment process. The final project will attempt to characterize (to include a knowledge-level description, if possible) the Mission Analysis process.

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